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Ecological Research Series

IMPACT OF ABANDONED WELLS ON GROUND WATER

Robert S. Kerr Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
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IMPACT OF ABANDONED WELLS ON GROUND WATER

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FOREWORD

The Environmental Protection Agency was established to coordinate administration of the major Federal programs designed to protect the quality of our environment.

An important part of the Agency's effort involves the search for information about environmental problems, management techniques, and new technologies through which optimum use of the Nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

EPA's Office of Research and Development conducts this search through a nationwide network of research facilities.

As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs to: (a) investigate the nature, transport, fate, and management of pollutants in ground water; (b) develop and demonstrate methods for treating wastewaters with soil and other natural systems; (c) develop and demonstrate pollution control technologies for irrigation return flows; (d) develop and demonstrate pollution control technologies for animal production wastes; (e) develop and demonstrate technologies to prevent, control or abate pollution from the petroleum refining and petrochemical industries; and (f) develop and demonstrate technologies to manage pollution resulting from combinations of industrial wastewaters or industrial/municipal wastewaters.

This report contributes to that knowledge which is essential in order for EPA to establish and enforce pollution control standards which are reasonable, cost effective, and provide adequate environmental protection for the American public.

William C. Galegar
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ABSTRACT

Unplugged abandoned wells are a hazard to our nation's potable ground water supplies. Today, millions of dollars of damage can be directly attributed to the contamination of ground water by improperly abandoned wells. The total impact of the hazard, however, is not fully understood, nor apparent. A review of case histories of ground water pollution caused by unplugged, leaking wells reveals the potential magnitude of the problem.

A survey of state laws concerning well abandonment procedures exposes a disparity in the regulations in and among different states. The laws in the traditional oil producing states are generally up-to-date and effective in dealing with abandoned wells. In the remainder of the states, well abandonment laws are ineffective or non-existent. Model legislation on abandoned wells is presented to contrast ineffective legislation with that which would give effective control. By examining the model legislation guidelines, state and local authorities can gain technical insight and legislative perspective, which will enable them to formulate and enact effective laws to protect their state's ground water supplies.

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SECTION 1

INTRODUCTION

Properly constructed water wells, oil and gas wells, and liquid waste disposal wells are not normally sources of ground water contamination, but when they are in a state of disuse and disrepair, casings and screens begin to corrode and the wells can become conduits through which contaminants can travel vertically through the boreholes.

An abandoned well's potential for adversely affecting ground water quality will depend on its original use, the local geology, the hydraulic characteristics of the subsurface fluids, and the type of well construction. When a well is abandoned, it is often covered by a board or by a sheet of metal that may or may not be welded to the top, in a feeble attempt to insure that the well does not become a public hazard. Unfortunately, such procedures fail to take into account the fact that the mere existence of an unplugged, abandoned well represents a great hazard to ground water quality. If left unplugged, the well endangers area water supplies and may, in fact, indirectly cause sickness or death to persons using that water for drinking.

An abandoned well frequently becomes a convenient receptacle for the disposal of wastes. People will throw anything into a well that will fit, including dead animals, automobile batteries, household garbage and a variety of liquid wastes.

The presence of unrecorded abandoned wells in areas subject to occasional or permanent flooding, such as the flood plains of streams, coastal areas undergoing subsidence, or areas flooded by artificial reservoir impoundments, permit the entrance of poor quality surface water into aquifers. The addition of a reservoir operating head can cause high inflows with an attendant danger of continuous contamination.

When wells penetrate saline or other aquifers under higher artesian head, deterioration of the casing results and the well becomes a conduit for the movement of poor quality water, or potentially hazardous fluids, into potable aquifers.

In addition to abandoned water, oil and gas wells, there are literally hundreds of thousands of abandoned mineral exploration wells, test borings, and seismic shot holes. These open holes permit water to migrate freely from one aquifer to another. A fresh water aquifer may thus be joined with a polluted aquifer or a deeper saline aquifer, or polluted surface water may drain into fresh water zones.

Many state regulations governing well abandonment are not comprehensive enough to insure adequate plugging of an abandoned well, and few states are capable of enforcing any regulations which may exist. Furthermore, since regulations vary greatly from state to state, particular states are reluctant to improve their regulations, when surrounding states call for less stringent well abandonment requirements. Listed below are some examples of this type of variability (U.S. EPA, 1976):

> Oregon requires that any well that is to be permanently abandoned shall be filled in a manner so as to prevent the well from being a channel allowing the vertical movement of water and a possible source of contamination of the ground water supply.
>
> The Texas regulation specifies that the well be filled with cement to the land surface, but also specifies alternatives depending upon whether there is undesirable water above or below the fresh water zone.
>
> The North Carolina regulations contain several specific requirements, including the specific stipulation that in the case of gravel packed wells in which casing and screens have not been removed, the casing shall be perforated opposite the gravel pack at intervals not exceeding 3 meters (10 feet). It specifically allows casing and screen to be salvaged. It requires that bored wells be completely filled; for wells in unconsolidated formations, it requires that this filling be done by introducing cement grout through a pipe extending to the bottom of the well which can be raised as the well is filled.
>
> A regulation of the San Joaquin Local Health District, California (in that state regulations are local, adopted under state recommended standards), requires "destruction" of any well that no longer serves a useful purpose, or has fallen into such a state of disuse or disrepair that it may become a source of impairment to ground water quality. The regulation is thorough, requiring that the interior of the casing first be cleaned to eliminate obstructions that might interfere with sealing procedures. It specifies filling of the well with the following additional requirement:
>
> > If there is no annular seal or if occurrence is unknown, the casing shall be perforated upward beginning just above the filler material for a distance of approximately 1.5 meters (5 feet). Grout shall be applied above the filler material in such a manner that the grout will be forced out of the holes, forming a barrier to the vertical movement of water.
>
> The regulation also requires, for protection of the seal and to facilitate future use of the land site, that a three foot hole be excavated around the well casing, the casing

cut off 15 centimeters (6 inches) above the bottom of the hole, and that during sealing operations, grout used to fill the well be allowed to spill over into the excavation and fill it for a thickness of 30 centimeters (1 foot) to form a cap which has a diameter of at least 30 centimeters (1 foot) greater than the diameter of the originally drilled hole. The excavation is then filled with soil.

A San Joaquin County ordinance authorizes the district health officer to destroy any well that is polluted or so located as to become polluted or is a safety hazard, and to recover the cost of destruction from the owner of the property on which the well is located.

The National Water Well Association and American Water Works Association have prepared recommended water well abandonment standards. It is the intention of these two agencies that each state consider these recommended standards as a minimum necessary requirement for proper well abandonment (Appendices A & B).

Ground water contamination caused by abandoned wells could be practically eliminated through education of state and federal regulatory agencies, and the general public. Increased awareness of the problem should lead to new regulations and more stringent enforcement of these regulations.

SECTION 2

CONCLUSIONS

The leakage of contaminated or highly mineralized water through abandoned wells and unplugged exploration holes has led to insidious ground water pollution problems. The scientific community and the state regulatory agencies have only recently realized the potential magnitude of the problems created by improperly abandoned water, gas, and oil wells. It is likely that the full impact of improperly abandoned wells in the United States will not be entirely recognized for years to come.

Areas where ground water contamination has resulted from improper well abandonment are subject to the economic and social hardships related to the loss or impairment of the groundwater resource.

It is neither technically nor economically feasible to plug all existing abandoned wells and exploration holes. Steps must be taken, however, to insure that wells and exploration holes abandoned in the future will be properly plugged.

Administrative controls are needed for the drilling of exploration holes.

Unsealed, abandoned wells and exploration holes constitute a hazard to public health, safety, and welfare, and to the preservation of ground water resources. The sealing of such wells presents a number of problems, the character of which depends upon the construction of the well, the geologic formations encountered, and the hydrologic conditions.

Any permanently abandoned well should be completely filled in such a manner that vertical movement of water within the well bore, including vertical movement of water within the annular space surrounding the well casing, is effectively and permanently prohibited and the water is permanently confined to the specific strata in which it was originally encountered.

A well should always be checked before it is sealed in order to insure that there are no obstructions which could interfere with effective plugging operations. Removal of casing from some wells may be necessary to assure placement of an effective seal. If casing opposite water bearing zones cannot be removed, it should be split with a casing ripper to assure proper sealing of these zones. At least the upper portion of the casing should be removed to prevent surface water from entering the water bearing strata by flowing down the casing. This operation is not necessary if the annular space around the outside of the casing was cemented when the well was completed.

Grout of any type, when used as a sealing material below the water level in the well, should be placed from the bottom up by methods that will preclude segregation or dilution of material.

Every effort should be made to disinfect wells prior to abandonment. All materials, such as water, sand, and gravel, to be used in the abandonment process, should be disinfected.

The best way to reduce or eliminate the detrimental effect abandoned wells can have on ground water is to create an awareness of the problem through education of state and federal agencies, of water well contractors and of the general public. This educational program must also include instruction in the technology necessary to properly seal abandoned wells.

If those states that have had the worst problems associated with abandoned wells can successfully eliminate ground water contamination due to these wells, then it is a worthwhile goal for all states to strive toward elimination of ground water pollution resulting from well abandonment.

SECTION 3

RECOMMENDATIONS

RECOMMENDED REGULATIONS FOR WELL ABANDONMENT

Nationwide uniformity of well abandonment regulations and procedures is probably unattainable and undesirable. However, each state should adopt minimum regulations to assure the protection of ground water quality.

The National Water Well Association recommends that the states incorporate the following provisions in any well abandonment legislation:

1) A listing of well abandonment procedures should be written for the different hydrogeological environments and types of wells that may be encountered in the state. One single well abandonment method will not be suitable for all wells and may be too much of an economic burden to be considered by a well owner or by a water well contractor.

2) States should make provisions for plugging of all existing abandoned wells. This includes wells that were abandoned before passage of regulations. Without some type of retroactive recourse, vast numbers of wells would remain a potential channel for ground water degradation.

The state could provide funding through which the agency in charge of well abandonment may trace all abandoned wells and either compel the owner to seal the wells, or permit state funds to be used to seal the wells.

3) All abandoned wells and the equipment and materials used to abandon wells should be disinfected to protect aquifers from bacteriological contamination, as is required during well construction.

4) Manpower and funding must be provided for proper enforcement of well abandonment regulations. Penalties must be established and used if responsible parties fail to comply with state regulations.

5) Well owners should be required to obtain prior approval from the regulatory agency of the drilling method and design and construction features of the well before a drilling permit is issued. When work on the well is finished, a driller's log and completion report should be filed with the proper state agency. This will aid in defining the procedures required to plug the well when it is abandoned.

6) Authority should be provided for the respective state agencies to trespass and to inspect the workmanship during or after the plugging of an abandoned well.

7) If a well is to be abandoned either temporarily or permanently, the owner should be required to notify the responsible state agencies. Such notification may simplify the work of a state agency if ground water contamination should develop in the area around the inactive well.

8) The state regulatory agency governing well abandonment should have the right to plug an abandoned well and assess the owner for the costs. In addition, a state fund should be established to permit plugging of abandoned wells where legal ownership cannot be ascertained.

9) State well abandonment regulations should be applicable to most subsurface excavations including, but not limited to water wells, gas and oil wells, seismic test holes, core borings and test holes, geothermal wells, and all kinds of injection wells. The goal of the regulations should be to provide for the restoration, as nearly as possible, of those subsurface and surface conditions that existed prior to drilling, boring, digging or augering. The purpose of the regulation is to prevent contamination of aquifers by surface waters and the interchange of fluids between aquifers.

The regulations should include procedures for abandoning wells, require inspection of the well during or after abandonment, and provide for enforcement and for penalties if the responsible person or agency fails to comply with the regulations. These penalties should be clearly delineated in the regulations.

10) Persons who drill holes, wells, or excavations to be used for the exploration of underground resources should be licensed by the state regulatory agency. Failure of the contractor to comply with any state well construction or abandonment regulations would jeopardize his right to work in that state.

State regulations should require that the owner of the well inform the proper state agency of any intention to abandon the well. Upon completion of the abandonment, the contractor who has done the work should file a report with the state certifying the methods used to abandon the well. No one but a well contractor should be permitted to seal a well.

The contractor would be responsible for the way the well is sealed, and should be held legally accountable for any damage to persons or to the environment that may occur because of improper sealing techniques.

11) Appendix A consists of the recommended procedures for well abandonment written by the National Water Well Association for the U. S. Environmental Protection Agency. These procedures represent the recommended minimum requirements for all states.

12) Every person intending to drill, bore, or in any manner excavate an opening in the earth for the purpose of evaluation of underground resources, including, but not limited to, metallic and non-metallic deposits, oil and gas, coal, water, and brine, should be required to obtain a permit from the proper regulatory agency. The permit application would describe the location of the hole or block of holes, their purpose, estimated depth, type and amount of casing, if any, hole diameter, water level, type of well, permeability,

thickness and quality of water in the aquifers that have been encountered, and proposed plugging procedures. Such information would simplify the process of locating the well if it is abandoned, of determining if it may be causing aquifer contamination, and of choosing the proper abandonment technology.

SECTION 4

CASE HISTORIES OF GROUND WATER POLLUTION CAUSED BY WELL ABANDONMENT

Disuse of a well leads to its rapid deterioration and increases the potential for ground water contamination.

Although most states require that an abandoned well be plugged to insure that it does not constitute a public hazard, most abandonment statutes are less than ideal.

As rural areas increase in population, the local populace is encouraged to give up the individual domestic supply well in exchange for a public water supply. The public water supply sometimes takes the form of a surface water impoundment. When the reservoir begins to fill with water, hundreds of unplugged abandoned wells may be submerged. When the water level reaches higher levels, hydraulic pressure will cause flow of water into the aquifers tapped by the submerged wells. The introduction of surface water directly into the abandoned well bores increases the danger of contamination to the aquifer.

Properly constructed water wells, oil and gas wells, and liquid disposal wells are not normally sources of ground water contamination. However, where a casing has been corroded or ruptured, where well screens or the open borehole interconnects two separate aquifers, or where the surface casing is not adequately sealed, wells can serve as a means for transmission of pollutants from one aquifer to another or from the land surface to the aquifer.

The factors leading to well deterioration and consequent ground water contamination, discussed in the preceding paragraph, are most typical of wells that are no longer being used or properly maintained.

Surface drainage into a well usually can be easily remedied. However, if an abandoned well has deteriorated at depth, the problems and causes of ground water contamination become difficult to detect, much less correct.

Of concern are wells that penetrate saline or other aquifers under high artesian heads. When a well is abandoned, deterioration of the casing results in the well becoming a conduit for movement of poor quality water or potentially hazardous fluids into potable aquifers.

Ground water contamination can occur whenever a hole is drilled from the surface into one or more aquifers. Thus, test borings, seismic shot holes, abandoned observation wells, and test wells also represent potential sources of ground water contamination.

Most states are not fully aware of the problems associated with abandoned wells. Except for an occasional water quality deterioration complaint from a well owner, it is likely that most states remain unaware of the impact of abandoned wells on ground water. Typically, a homeowner may complain of the smell of oil or hydrogen sulfide in his water. A public health official checking the problem may find that the only potential source of such contamination is an abandoned oil well nearby that has possibly penetrated a coal seam or a depleted oil reservoir. The well casing has probably corroded, allowing high pressure fluids to rise upward from great depth and to enter the aquifer that had previously provided potable water.

Case histories of known ground water quality degradation from abandoned wells are not as readily available as might be suspected even though there are an estimated 2,000,000 abandoned wells in this country. Most occurrences have gone unrecorded because many abandoned wells are found in remote rural areas, and the area contaminated is usually very localized.

ABANDONED WATER WELLS

When it was discovered that the quality of water furnished by a municipal well in Avon, South Dakota, was markedly different from the quality of water obtained from nearby wells tapping the same aquifer, the United States Geological Survey state office investigated the phenomenon (Jorgensen, 1968). An aquifer test and analysis of water samples showed that the anomalous water quality of the municipal well in Avon was caused by leakage from a nearby abandoned well that tapped another aquifer.

During an investigation of the ground water supplies of the Atlantic City region of New Jersey, Thompson (1928) noted that some production wells in the study area were contaminated with chlorides. The cause of the high chloride content was discovered to be improperly plugged abandoned wells that permitted interaquifer transfer of water between fresh and saline aquifers.

Sayre (1937) reported that the ground water of Pliocene Sands in Texas was locally contaminated by chlorides. He theorized that the localized contamination was the result of casing corrosion in active and abandoned water wells, which permitted highly mineralized water from shallow strata to flow into the deeper Pliocene aquifer.

In two studies of the ground water resources in the Baltimore, Maryland, area, Bennett and Meyer (1952) reported that from 1850 to 1950 an estimated 1,500 wells had been drilled. By 1945 approximately 1,250 wells had been abandoned, but only 150 wells, or 12 percent, had been plugged. As many as 1,140 of these abandoned wells are no longer accessible because they are covered by buildings, highways and other structures. It is possible that this construction may have damaged well casing, increasing the chance of a well becoming a point of contamination. Nonetheless, it cannot be assumed that all these unplugged wells are sources of ground water contamination. Many of the wells do not penetrate more than one aquifer, or do not encounter saline water. In addition, it is probable that some abandoned wells have collapsed and that their boreholes are filled with formation materials.

In 1956, the American Brass Company constructed three high-capacity water wells at their plant in Terre Haute, Indiana (Johnson National Drillers Journal, May-June, 1957).

> The engineers were rudely surprised when the water pumped from each of the wells proved to be contaminated with salt. The water was unusually hard and contained 10 to 30 times more chloride than the ground water pumped by other industries in the general area. The wells were completed in glacial outwash material.

A systematic investigation revealed the presence of an unplugged abandoned test hole about 606.6 meters (2,000 feet) from the new water supply wells. The test hole had been drilled at an earlier date during a period of oil exploration. The test bore contained water with 8,600 ppm chlorides and a static water level 8.5 meters (28 feet) higher than the static level of the fresh water in the glacial formation. This abandoned test hole had never been plugged. It proved to be the source of the contamination.

The Florida Department of Environmental Regulation has made reference to a number of known cases on ground water contamination. (Craig L. Helping, Written Communication, 1976):

1) A conservative estimate would indicate that there are about 4,000 abandoned wells in Florida with more being abandoned each year. The state requires notification for any well which is to be abandoned; however, this has largely been neglected and very little accurate information is available. In addition, most of the information on hand is of recent vintage. Older records of abandoned wells are generally non-existent.

2) One particular situation which has created special problems is that of abandoned artesian wells. Large portions of Florida are underlain by a series of limestone aquifers under sufficient artesian head to cause wells to flow at the land surface during a portion of the year. In general, these separate producing zones are sealed from each other by rather effective aquicludes.

   Each aquifer has a different water quality and artesian head. Where this type of hydrologic system exists, both artesian pressure and total dissolved solids increase with depth. This increases the potential of interaquifer mixing and contamination in instances of improper well design and deteriorated well casing.

3) Water table seepage around well casings or via the well borehole provides the potential for ground water contamination from above.

4) One special problem has been encountered in this state with regard to abandoned wells. Some flowing wells which have been abandoned and allowed to deteriorate have created ponds which pose severe problems in regulation. Other artesian wells have been cut off below ground level, capped, and then a building or even a roadway has been constructed on top of them. Once the casing and cap deteriorate sufficiently, the well begins flowing wildly again, creating significant problems which are most difficult and expensive to correct.

5) Abandoned wells have been found in every area of the state, many in remote or inaccessible areas. The location of these wells is hindered by the lush, semi-tropic vegetation and marshlands. Location, of course, is only the first step toward implementing regulations. Quite often, once a well is located, it proves to be impossible to get logging equipment and well plugging equipment to the site. In such cases, it is difficult to enforce remedial regulation.

   An illustration of this type of problem involves a number of flowing artesian wells which are submerged in the Gulf of Mexico off the west coast of Florida. There are approximately 50 submerged, flowing wells along the 83 kilometers (52 miles) of coastline of Managee and Sarasota Counties. These wells, typically 5 to 9 centimeters (2 to 6 inches) in diameter and 45 to 243 meters (150 to 800 feet) deep, were originally drilled to provide domestic water supplies to residents of the various barrier islands.

   Sections of the barrier islands have been eroded during severe storm and hurricane activity. Depending upon the amount of erosion, some wells are now located from within a few feet of the present shoreline to a distance of about 152 meters (500 feet) out into the Gulf.

   Having been subjected to electrolysis and naturally corrosive conditions, the majority of these wells have deteriorated to a point where they are submerged at all times, and no longer are equipped with valves or caps to prevent the loss of fresh water.

   Salt water may also enter an abandoned well and directly contaminate portions of the fresh water aquifer

when the artesian pressure declines to a point where the flow is overcome by the pressure of the salt water above.

The wells which are located beyond the mean high water line legally become the property of the State of Florida and should be brought into compliance with state regulations. Locating these wells has become a problem of major proportions. Since the majority of the wells are submerged, it is impossible to locate them by conventional means. Scuba diving is also impractical since the search area has 152 meters (500 feet) by 83 kilometers (52 miles) dimensions.

Discussions of the problem with the National Aeronautics and Space Administration (NASA) has led to a joint research and development project by NASA and the Florida Department of Environmental Regulation. The objective of the experiment has been to use airborne thermal scanner imagery in an attempt to locate the wells by detecting temperature differentials caused by the flowing wells on the surface of the Gulf of Mexico.

The majority of artesian wells in the project area, depending upon depth, flow water of approximately 26° - 28°C (80° - 83° F), year round. By conducting the flight missions during the winter months when the temperature of the Gulf of Mexico is suppressed to 14° - 16° C (58° - 60° F), the state is assured to the best possibility of detecting the surface thermal anomalies which submerged, flowing wells may cause. The thermal imagery gathered during this experiment is now being analyzed to determine and map all signatures which may indicate a well. Extensive field checking will then be done to precisely locate all of the wells. After the location and verification aspects are completed, the wells will be plugged according to specifications.

ABANDONED OIL AND GAS WELLS

The leakage of contaminated or highly mineralized water through abandoned oil and gas wells and unplugged exploration holes has led to insidious ground water pollution problems.

In Michigan, thousands of holes were drilled for exploration of oil, gas, and coal resources before the turn of the century. Leakage over the past 80 to 100 years of billions of liters of highly mineralized solutions through these open abandoned holes has created widespread problems.

Leakage of acid mine drainage through old oil and gas test wells and other open holes has caused extensive ground water pollution in the coal fields of Pennsylvania and elsewhere in Appalachia.

Regulations of the Kentucky Water Pollution Control Commission in October, 1958, required disposal wells to inject brines at depths of 53 meters (175 feet) or more below the local drainage. Pressure disposal into porous zones below the New Albany Shale of Devonian age was permissible from March, 1959, to March, 1960. The Louisville Limestone of Silurian age underlying the New Albany Shale became a major brine disposal zone at this time. This formation was previously penetrated, however, by several abandoned gas and oil test wells drilled in the 1920's and 1930's, which allowed the brines to move upward and contaminate the fresh-water zones above. The brines changed the potable ground water from a calcium bicarbonate type containing moderate amounts of magnesium and sulfate to a sodium chloride type. Chloride concentrations prior to oil production generally were less than 60 mg/l; after oil production, chloride concentrations were as high as 51,000 mg/l.

Abandoned, unplugged wells from frantic wildcat drilling in Taylor County, Kentucky, hampered brine disposal through injection wells. When brines were injected under pressure, the abandoned wells in the area also begin to flow brine.

During the development of the Greensburg oil field in the fall of 1958, many wells and springs formerly yielding fresh water were reported to have "gone salty." Brines discharged from oil wells in the Greensburg oil field were the probable source for the increased salinity. The ground water contamination was concentrated in the areas of heavy brine production in Green and Taylor Counties, but was noticeable as far away as Brownsville, about 161 kilometers (100 miles) downstream.

Highly mineralized water in the Jamestown, New York, area is believed to be moving upward from deep beds of salt underlying the western and southern portion of the area at depths ranging from 457 to 610 meters (1,500 to 2,000 feet) below mean sea level. These salt deposits were penetrated by deep test wells drilled for oil and natural gas. Several of the test wells also penetrated zones containing very salty water at much shallower depths than the rock salt. The mineralized water results from deep circulation of fresh ground water down to the salt beds. Most of the upward movement may be along natural breaks in the rocks. However, some of the water is moving upward through abandoned oil and gas test wells that have not been adequately plugged (Crain, 1966).

In Chemung County in western New York, adjacent to the Pennsylvania border, the concentrations of chloride and total dissolved solids have been increasing. The upper bedrock of Chemung County is composed of a sequence of sandstone and shale, overlain by glacial drift. Within the major stream valleys, the sand and gravel deposits are productive aquifers. Elsewhere, the

bedrock aquifer is utilized. Salt beds and zones of highly mineralized water are known to underlie the area at depth. Although never a highly productive petroleum area, a number of gas wells were drilled and later abandoned. Many of these old wells are conduits for the upward migration of the mineralized water. Natural chloride content of the shallow fresh-water aquifers in the county is less than 10 mg/l; concentrations of this constituent in water from domestic wells contaminated by brine from the deeper gas strata range from 100 to 500 mg/l. Analyses of water from domestic, industrial and municipal wells in the Susquehanna River Basin in New York indicate similar conditions (Miller et. al., 1974).

> A classic example of problems that can arise from abandoned wells has occurred in Colorado. In 1915, an oil test hole was drilled in west-central Colorado to a depth of 560m. (1,837 ft.). This well encountered warm, mineralized water. Fifty-three years later, on May 9, 1968, the well was found to be discharging 7,338 cu m/d (1,350 gpm) of brackish water with a concentration of 19,200 mg/l dissolved solids. It was estimated that this flow contributed 52,000 metric tons (57,000 tons) of dissolved solids per year to the White River. The well was subsequently plugged, after which the hydrostatic pressure built up, causing other non-flowing wells in the area to flow, and creating saline seeps in the vicinity of these wells. (Miller, et. al., 1974).

Wait and McCollum (1963) report that an abandoned, unplugged oil test well in Glynn County, Georgia, yields salt water with a chloride content as high as 7,780 mg/l. The 140 meter (4,615 foot) well penetrates both fresh-water and salt-water aquifers. The well bore serves as a conduit to connect the salt-water and fresh-water aquifers. Because the pressure is greater in the deep salt-water aquifers than in the shallower fresh-water aquifers, the salt water flows upward into the fresh-water aquifer.

Unplugged wells and artesian brine have resulted in reported flowing salt water wells in Know, Hopkins, and Young Counties, Texas. In Hopkins County, one abandoned oil test well was flowing between 100 and 125 barrels per day of brine water before it was plugged (Scalf, et. al., 1973).

Fink (1965) reported to the Texas Water Commission that ground and surface-water contamination near Harrold, Texas, may have been caused by any or all of three potential sources:

1) Brine injection wells where corrosion of the casing has taken place;

2) Injected brine that may be entering inadequately plugged, abandoned oil wells;

3) Brine discharge into unlined surface pits.

Fink indicates that the majority of the abandoned oil wells in the area were inadequately plugged, thereby increasing the chances for contamination from the second source.

In a 1962 study, Burnitt suggests that an improperly plugged oil well may be permitting gas and brine fluids to contaminate the near surface aquifer. Burnitt suspects that deterioration of the surface casing remaining in the well in question has resulted in creating an open bore from the surface down to the top of the cement around a poorly placed plug.

OTHER TYPES OF ABANDONED WELLS

A study (Bond, 1975) of the influence of seismic shotholes on ground water quality was done in Montana. It showed that little if any contamination occurred. Since the shotholes were typically less than 60 meters (200 feet) in depth, few if any artesian aquifers were encountered, reducing the possibility of inter-aquifer transfer of water. In addition, it appeared that all shotholes sealed themselves within a year, as a result of the collapse of sand, clay or silt in the borehole. However, the Montana findings may not apply elsewhere.

Rold (1971) points out that in many areas, shotholes are 90 meters (300 feet) or deeper and can provide a ready admixing of salt and fresh water aquifers. These holes can deplete the pressures of shallow artesian aquifers and allow shallow polluted waters or alkaline waters to enter deeper potable aquifers.

Underground gas storage is defined as storage in rock of synthetic or natural gas. The gas may be stored in gaseous or liquid form, and is often injected into depleted oil or gas reservoirs or in aquifers.

> Undergound gas storage fields present a potential for contamination of usable ground water by leakage of gas through the confining beds, through improperly plugged wells . . . (U.S. EPA, 1973)

Deep well injection is a method commonly used to dispose of oil field brines.

Payne (1966) discussed how brine injection coupled with local abandoned wells can represent a hazard to fresh ground water in Texas. Other authors, Burnitt, et. al. (1962), Fish (1965), and Preston (1969), had similar experiences with brine injection and abandoned wells.

The Herscher underground natural gas storage field, located one mile south of the Village of Herscher in Kankakee County, Illinois, was the site of ground water pollution by natural gas. Although no conclusive evidence was developed to prove how gas escapes from the underground storage formation, abandoned oil wells were suspected.

The Herscher reservoir structure underlies approximately 60.7 km^2 (15,000 acres) of rural land. Geologically the storage structure is a closed

anticline or dome. It is shaped like an inverted saucer that provides the geologic trap necessary for large-scale storage of natural gas. Five hundred and thirty-three meters (1,750 feet) below the ground surface is the apex of a very porous and permeable bed of sandstone (the Galesville Formation) which forms the reservoir for the storage field.

The existence of the structure had been known for many years. Following the turn of the century, approximately 20 oil wells had been drilled to an average depth of 60 meters (200 feet) where oil and a small amount of gas had been encountered. After a short period of fruitless pumping, these wells were abandoned. No attempt to plug the wells was made. The casing was cut off below the ground surface and farming was continued on the site.

During August, 1953, after gas had been injected for 4 months, a total of 33 village water wells became active with gas. It has been postulated that one or more of the old oil wells had actually been drilled into the Galesville Formation, thereby allowing natural gas to escape into the overlying strata.

Although it was not conclusively proved that abandoned wells were the prime cause of contamination, the chances are good that they were.

SECTION 5

STATE WELL ABANDONMENT REGULATION SURVEY

The degree to which state agencies understand the potential impact of abandoned wells on ground water quality is reflected in their well abandonment regulations. Alaska, Indiana, Iowa, New Hampshire, Connecticut, Kentucky, Massachusetts, Mississippi, and the District of Columbia claim that their states have no problems with abandoned wells, or that abandoned wells do not exist within their boundaries. Therefore, these states have no regulations to deal with well abandonment. Louisiana and Texas have long realized the effect that abandoned wells can have on potable ground water. Both of these states have thousands of abandoned water, oil, gas and exploration wells, seismic shotholes, and brine and liquid waste disposal wells. Louisiana and Texas economies are closely tied to their subsurface natural resources, such as oil, gas, and water, and depletion of any of these resources could result in economic disaster. Consequently, these two states have formulated extremely detailed and comprehensive well abandonment regulations which fully describe the procedures to be used for each type of well and for wells that penetrate different hydrogeological environments.

The majority of states do have regulations to deal with the hazards of well abandonment, but they are not uniform in content. In some states, the regulations are useless and only require that all wells be filled to prevent injury or death to people and animals who might fall into one; other states have regulations that exceed suitable well abandonment requirements. The variability of these laws is indicative of the lack of understanding of the problems associated with well abandonment.

Well abandonment regulations are only as good as their enforcement, and enforcement is a problem that confronts most states. Only Louisiana, Florida, Hawaii, Missouri, New Jersey, Texas, Utah, West Virginia and Wisconsin have provisions for enforcement of well abandonment procedures. Some states leave enforcement up to county or local agencies. Other states simply do not have the manpower to carry out inspection and enforcement at any level.

In states where well owners are responsible for paying the costs of well abandonment, one finds that owners are less than enthusiastic about reporting an abandoned well. Usually, state regulatory agencies do not find out about an abandoned well until they are asked to evaluate the cause of some localized ground water contamination.

The problem with owner abandonment is becoming most evident in regions where rural water supply districts have been created. After a homeowner,

farmer, or small business has been assessed for a hook-up to public water, they are generally reluctant to bear the additional expense of proper well abandonment.

A further obstacle to the proper sealing of an abandoned well is that some states permit the owner to seal or plug the well. The procedures of well abandonment should be carried out only by drilling contractors who have a complete understanding of the difficulties of properly plugging a well, the reasons for plugging, and the equipment necessary.

One of the best ways to analyze the practicality of well abandonment regulations is to review those of each state. To assist the reader in evaluation, there is a general commentary on the different regulations at the end of the review. When a particular regulation is worthy of commendation or criticism, a brief comment immediately follows.

ALABAMA

"All wells shall be permanently abandoned in the following manner: The well will be filled with a puddled clay material containing 50 mg/l of chlorine to within 6 meters (20 feet) of the top of the well. The top 6 meters (20 feet) shall be filled with cement grout or concrete."

ALASKA

No specific well abandonment regulations.

ARIZONA

"Abandoned wells and test wells should be sealed by restoring the controlling geological conditions which existed before the wells were drilled. Whenever feasible, the wells should be completely filled with concrete."

Comments: Regulations in Arizona and Alabama fail to describe specific procedures for well abandonment, to require inspection and notification of well abandonment, and to enforce the regulations.

ARKANSAS

"Wells drilled for water and then abandoned for any reason shall be properly protected to maintain the original quality of the ground water source. The abandoned well must be grouted to a minimum depth of 3 meters (10 feet) below ground surface. It is the contractor's responsibility to seal out any and all contamination, such as surface water or seepage, by placing the grout to the necessary depth. The enactment and enforcement of the regulation is the responsibility of the Arkansas Committee on Water Well Construction."

CALIFORNIA

The purpose of well abandonment in California is to assure that the ground water supply is protected and preserved for future use, and to elimin-

ate the potential physical hazard that exists. All abandoned wells shall be destroyed in such a way that they will not produce water or act as a channel for the interchange of water.

The objective of California's regulations is to restore as nearly as possible the subsurface conditions in existence before the well was constructed. To accomplish this objective, the borehole first must be cleared of all obstacles and, if possible, the casing shall be removed. In unconsolidated materials, in an unconfined aquifer where ground water is within 15 meters (50 feet) of the surface, the upper 6 meters (20 feet) of the well shall be sealed with impervious material and the remainder of the well filled with sand, clay, or other suitable inorganic material. Where wells penetrate several producing zones, sand or clay can be placed opposite the producing zones, but an impervious plug a minimum of 3 meters (10 feet) in length must be placed between the zones to prevent the vertical movement of water. Where wells penetrate creviced or fractured formations, cement or concrete shall be placed opposite the formation. Where neat cement, cement grout, or concrete is used, it must be poured in one continuous operation. Where artesian flow is present, special methods will be used during sealing operations. To assure that the well is filled and that there has been no jamming or "bridging" of the material, verification shall be made that the volume of material placed in the well at least equals the volume of the empty hole.

The regulation also describes sealing and fill materials.

Enactment and enforcement of the regulation is up to the counties and cities of the state. Twenty-nine of 58 counties have enacted these regulations, while 118 of the 411 incorporated cities have adopted the well abandonment ordinances. How well these regulations are enforced is unknown, but can be assumed to vary greatly from county to county, and city to city.

> Comments: There is a vast difference in the detail of the Arkansas and California ordinances for well abandonment as compared to those of Alabama or Arizona. Most noteworthy is the fact that procedures for well abandonment are described, and that they vary for different subsurface environments.

COLORADO

Small diameter wells in unconfined materials can be filled with sand and gravel up to the static water level, then with inert material to within 3 meters (10 feet) of the surface. The top 3 meters (10 feet) shall be filled with concrete, neat cement, or other approved material. Requirements for large diameter wells in unconfined aquifers is similar except that inert fill material shall be used from the water table to the surface, and a permanent cover shall be placed on top of the casing.

Water wells completed in confined formations shall be plugged with concrete, neat cement, or other approved material at the first impervious strata above each zone and cement grout from the surface to a depth of 3 meters (10 feet).

The Colorado ordinance permits either a contractor or well owner to plug an abandoned well.

Comments: When a licensed water well contractor is hired to plug an abandoned well, the result is generally more satisfactory than when a well is plugged by an owner who does not know the proper abandonment procedures. Once a well is filled or plugged incorrectly, it is difficult to get the owner to dig it up and plug it properly.

CONNECTICUT

No regulations.

DELAWARE

All wells must be abandoned by a licensed water well contractor. Notification of an abandoned well must be sent to the Water and Air Resources Commission, who under unusual circumstances may specify special techniques for well abandonment. In other cases, wells must be filled and sealed with puddled clay or concrete.

DISTRICT OF COLUMBIA

No well abandonment regulations.

FLORIDA

Florida's ordinances are on a par with those of California and Arkansas. The state specifically designates procedures to be used for abandoning artesian and non-artesian wells. The regulations shall be administered and enforced by the Department of Natural Resources and the five Water Management Districts. During and after abandonment, the enforcing agents can inspect the well site to insure that proper procedure is or has been followed.

GEORGIA

Abandoned wells must be plugged at the owner's expense. The contractor must notify the Environmental Protection Division of the State Department of Natural Resources within 30 days of plugging.

GUAM

A permit is required to abandon a well. The purpose of proper well abandonment shall be to prevent the interchange of water in different aquifers and to protect the ground water quality of potable aquifers. All obstacles, including casing when possible, will be removed before plugging. Where the well casing cannot be removed, it shall be perforated to permit cement to enter and form an adequate seal in the annular space. The regulations of Guam are nearly identical to those of California.

HAWAII

It is up to the well owner to have a well sealed after it is abandoned to protect ground water resources against wastage and contamination. Inspection shall be conducted by persons from the Department of Land and Natural Resources. All wells shall be abandoned by filling from bottom to top with neat cement grout. Violation of these regulations is a misdemeanor, and thus punishable as prescribed by law.

Comment: Hawaii is one of the few states that clearly describes penalties for failing to comply with state regulations. The request to have a well filled entirely with neat cement may be unjustifiable because of economics. In this case, Hawaii would be better off providing alternative methods of plugging for different conditions encountered.

IDAHO

Wells constructed under Idaho Minimum Well Construction Standards, where the casing and seal are intact, must, at a minimum, have a 6 millimeter (0.25 inch) thick steel water-tight plate covering the top of the casing and welded to the casing. Water wells which have had the casing removed or which were not constructed in accordance with minimum well construction standards, upon abandonment shall be filled with cement grout, concrete, or puddled clay.

If the well is artesian, a cement grout, concrete plug, or packer, approved by the Director, should be placed in the confining stratum overlying the artesian zone to prevent subsurface leakage from the artesian zone. The remainder of the well must be filled with cement grout, concrete, or puddled clay.

Abandoned waste disposal and injection wells constructed in accordance with Idaho Minimum Well Construction Standards and where the casing and seal remain intact must, at a minimum, have a steel, water-tight plate fully covering the top of the casing and welded to the casing. Abandonment procedures will be specified by the Director at the time authority is requested to abandon the disposal well.

ILLINOIS

Water well abandonment regulations are administered by the Illinois Department of Mines and Minerals. There are separate regulations for abandoned water wells and abandoned oil, gas, and salt water disposal wells. The water well regulations call for removal or tearing of the casing. Neat cement shall be used from the bottom to the top of the water table; clay shall then be used to the top of the well. Abandonment is to be done by a certified contractor.

In unconsolidated formations, sand and gravel shall be used opposite water yielding zones. Creviced rock formation wells shall be entirely filled with neat cement. Noncreviced rock formations shall be filled with sand or gravel with 3 meters (10 feet) of cement or clay at the top. Wells penetrat-

ing more than one aquifer shall be sealed in such a way that inter-aquifer exchange is prohibited. A cement plug not less than 9 meters (30 feet) in length shall be placed opposite each aquifer. Artesian wells may have to be grouted under pressure. The state describes recommended procedures for different situations encountered. After sealing the well, the owner must sign an affidavit stating that the well has been sealed.

INDIANA

No well abandonment regulations.

IOWA

No state statutes regulating the abandonment of wells.

KANSAS

Kansas provides three different procedures for abandoning wells based on whether they penetrate confined or unconfined aquifers, or whether they are test wells.

A well which penetrates an unconfined aquifer shall have its casing cut off one meter (3 feet) below the ground surface. The hole shall then be filled with natural earth materials to the static water level, and from there with inert material to within one meter (3 feet) of the surface. The top of the casing shall be sealed with a concrete or steel plate.

Wells completed in confined and unconfined aquifers shall be abandoned by cutting off the casing one meter (3 feet) below the land surface, then plugging with concrete, neat cement or other material to the first impervious strata above each aquifer, and cement grout from a point one meter (3 feet) below the surface for a depth of at least 3 meters (10 feet). Natural earth materials can be used between the plugs.

Test holes shall be plugged within three days after testing with natural earth materials, neat cement, or concrete from bottom to top. Holes penetrating two or more aquifers shall be plugged in accordance with the preceding paragraph.

KENTUCKY

Kentucky has no statutes to regulate abandonment of wells.

LOUISIANA

To assure that wells are properly abandoned, their existence must be reported to the state, and abandonment work must be approved by the state. Inspection by the Louisiana Department of Public Works can be ordered at any time to determine if the work has been completed satisfactorily. The contractor in charge is obligated to file a completion form when abandonment work is finished. To assure that the well is properly sealed and that there is no bridging of material, it is recommended that the contractor make veri-

fication calculations and measurements to check that the volume of the material placed in the hole at least equals the volume of the casing or the hole to be filled.

The state can consider a well abandoned if a year or more has passed since the well has been used, or if the well is seemingly in a state of disrepair. A well can be left inactive if properly maintained.

An "abandoned hole" is a borehole that has not been cased. A hole will be considered abandoned if it has not been used in 30 days.

The well owner is responsible for well abandonment. Failure to comply with well abandonment procedures will result in action of the Police Jury of the Parish, which can then have the Department of Public Works notify the owner that he must have his well properly plugged within 30 days. If the work order is not followed, then the Department of Public Works can have the well plugged at the owner's expense.

The well or hole must be plugged by an experienced contractor. The well shall first be inspected so that the borehole or casing is free of obstacles. All plugging material shall be implaced under pressure or by circulation. The surface plug shall be at least 9 meters (30 feet) in length. The well shall be plugged form bottom to top.

A well less than 15 meters (50 feet) deep shall be plugged completely with cement slurry, neat cement, or fill material in sufficient amount to plug the hole and seal the annular space.

If a well is greater than 15 meters (50 feet) in depth and in an area where one or more fresh water aquifers are penetrated, then either: 1) the entire well shall be filled from the bottom to the top of the casing with cement, slurry, or 2) fill material shall be placed in the screen or in the open hole oppostie the producing aquifer. A bridge plug not less than 15 meters (50 feet) in length shall be set above the top of the screen. The remainder of the casing below the upper 9 meters (30 feet) shall be filled with fill material, above which a surface plug will be set.

If one or more saline aquifers are penetrated, the entire well casing and screen shall be sealed with cement slurry.

Additional but similar special provisions are made for wells which have had all or part of their casing removed, gravel packed wells, wells in which multiple zones have been screened, and of augered, bored or dug wells.

Seismic shot holes, cathodic-protection wells, saline-water wells associated with secondary recovery operation, brine wells, oil and gas wells, geothermal and geopressured wells, waste disposal wells, and holes and excavations used in the development and/or exploration of mineral resources are exempt from the preceding regulations. However, owners of such excavations are still legally responsible for the contamination of potable ground water resources due to their negligence or if their wells in any way endanger the health and welfare of the general public.

Comments: Louisiana has one of the nation's most comprehensive well abandonment regulations. Louisiana Department of Public Works officials report that contamination from abandoned wells has been virtually eliminated because of strict enforcement legislation.

MAINE

The state requires that abandoned wells be filled to prevent accident or injury to people or animals.

MARYLAND

Maryland requires that abandoned wells be plugged to prevent the inter-aquifer exchange of water of varying quality. The abandonment of wells is only permitted by a licensed contractor.

The first step in well abandonment is the removal of all obstacles from the well, including the casing. If the casing cannot be withdrawn it shall be perforated to permit the sealing of the annular space. Shallow, small diameter wells shall be entirely sealed. Sealing involves the use of concrete, neat cement, or bentonite clay. Wells in unconsolidated formations shall have the upper 12 meters (40 feet) sealed; the remainder of the well shall be filled. The process of filling involves the installation of material such as clay, silt, and gravel that has been thoroughly disinfected.

If a well penetrates several aquifers, sand or fill shall be placed opposite the producing zones and seal material shall be placed opposite the confining layers. Where a well penetrates creviced or cavernous rock, course material shall be used to fill the cavity, but sealing material shall extend from the top of the more competent rock units. A minimum of 3 meters (10 feet) of sealing material is required. Wells in non-creviced consolidated formations shall have 6 meters (20 feet) of sealing material in the non-creviced formation, and the rest of the well shall be plugged with fill material.

The state requires that all material be placed from the bottom up. Where cement or concrete is used, its placement should be continuous. After completion of the plugging, the contractor has 30 days in which to file a completion form.

Maryland has been unable to suitably enforce these regulations.

MASSACHUSETTS

Massachusetts has no statutes for the regulation of well abandonment.

MICHIGAN

Michigan requires that an abandoned well be filled and sealed by one of the following methods in accordance with the geological formations penetrated. It shall be done in a manner as to prevent the well from acting as a channel for pollution, or to prevent the escape of subterranean gases.

A report of the method of sealing shall then be filed with the health officer.

A well in unconsolidated deposits shall be filled with clean puddled clay, neat cement grout, or concrete grout.

The section of a well in a cavernous or creviced rock (such as cavernous limestone or basalt lava rock, creviced granite, etc.) shall be filled with concrete or neat cement grout or alternate layers of concrete or neat cement grout, gravel or stone aggregate. The filling shall be completed at the top by a layer of neat cement grout or concrete grout extending at least 6 meters (20 feet) above the top of the cavernous rock or to the ground surface.

The section of a well in a sandstone strata shall be filled with neat cement grout, concrete grout or sand. The filling shall be completed at the top of the formation by a layer of neat cement grout or concrete grout extending at least 6 meters (20 feet) above the top of the sandstone or to the ground surface.

The flow in a flowing well shall be confined and the well filled in accordance with preceding paragraphs, or the well shall be sealed by pressure grouting.

Abandonment of wells containing subterranean gases requires special precautions, and a casing in such a well shall be sealed with neat cement grout or concrete grout.

Debris or obstructions that may interfere with sealing operations shall be removed from the well.

Screens on nonflowing wells which terminate in the glacial drift shall be pulled and the casing filled with puddled clay or other approved material from bottom to top. If the casing is to be pulled, the hole shall be kept full of the grouting material while the casing is being pulled, adding more grout from time to time during the process. A few days after the casing is removed, a visit shall be made to the location to refill the hole after settling occurs, before final abandonment.

In plugging flowing wells in the drift, the difficulty is inversely proportional to the depth. In a deep well, a quantity of puddled clay shall be introduced heavy enough to overcome the flow, then cement shall be placed on top of the clay. In a shallow well, however, the column of clay fluid is occasionally not heavy enough to reverse the flow. In that case, a mud pump shall be used to pump in a high-density mud fluid through a swedged nipple on the top of the casing. Sometimes in shallow wells with very high heads, it is necessary to pump in cement mixed with enough chloride or other hardener to set up immediately.

The best way to insure a satisfactory plugging job is to leave the drive pipe in the hole and fill it with clay, neat cement grout or cement grout. If water is flowing up the outside of the casing, it is necessary

to "squeeze" cement up around the outside of the casing by pumping it down the inside. The casing shall remain in the hole when the well is plugged and be completely filled with grouting material. The casing is filled with grouting material to reduce corrosion.

Michigan requires that the well owner and contractor share the responsibility for proper abandonment.

MINNESOTA

Minnesota requires that the borehole of an abandoned well be filled in such a manner as to prevent contaminating materials from entering the water-bearing formations. All obstacles, debris and, if possible, casing shall be removed from the borehole. If the casing cannot be removed, it shall be perforated. Concrete or cement grout shall be used for sealing material; however, if the well is so large that the use of these materials is not practical, the filling materials shall be selected to restore natural conditions without exceeding the original permeability of the formation. The casing remaining in the hole shall be cut off 0.6 meters (2 feet) below the surface. The uppermost 3 meters (10 feet) of casing must be filled with cement or concrete grout. The remaining top 0.6 meters (2 feet) of the hole shall be filled with native top soil. Where concrete, cement grout, puddled clay or heavy drilling fluid is used for sealing, it shall be inserted in the well through a grout pipe from the bottom of the well upward to the surface under pressure, in one continuous operation. Special provision is made for the sealing of cavernous or creviced rock.

> Comments: While Minnesota recommends filling nearly all the borehole with cement or concrete, it realizes that this procedure is unfeasible in some cases and provides for filling some sections with other inorganic material. This is in contrast to the state of Hawaii which requires grouting of the entire well.

MISSISSIPPI

No state statutes regulating well abandonment.

MISSOURI

The state requires that whenever any well is abandoned, it shall be plugged or sealed as necessary to prevent pollution of subsurface waters.

An affidavit setting forth in detail the significant data in connection with the well and the procedure of plugging, signed by a qualified witness to the plugging and duly notarized, shall be filed in duplicate with the agency within 15 days after plugging is completed, except that upon application to and approval by the agency when a number of test holes of any one person are involved and drilling is on a continuing basis, reports may be submitted quarterly setting forth the significant hole data and plugging pro-

cedure. Unless prohibited by the Missouri Clean Water Law, such reports, upon written request, will be held confidential for one year. The agency may require the well owner or operator to replug any well where the plugging was not effective.

Any test hole which is drilled for underground exploration, and which penetrates into or through any aquifer which is, or may be used for a potable water supply, shall be plugged. Test holes which do not encounter the potable water aquifer may be refilled with the same material taken from the hole, or other non-polluting fill material, except that those drilled just preceding such active mining in the area, (example, coal mining, limestone quarry, etc.), do not have to be refilled or plugged until after such active mining has ceased.

MONTANA

The state of Montana has no statutes to regulate abandoned wells, but recommends procedures for well abandonment suggested by the Department of Health and Earth Sciences and the Montana Water Well Driller's Association.

NEBRASKA

The owner of a well is required to make certain that the well is abandoned in accordance with the rules and regulations of the Department of Water Resources. Written notice of well abandonment shall be provided to the Department within 60 days.

Wells abandoned previous to the effective date of the regulations are encouraged, but need not comply with regulations.

Before the borehole is filled, the well shall be checked to see if it is clear of obstructions. Where applicable, the casing shall be perforated or otherwise punctured to insure that sealing material fills not only the well casing, but the annular space and surrounding voids as well.

Wells in an unconfined aquifer shall be abandoned by filling the well with clean sand or gravel to at least the top of the aquifer. Inert material shall be implaced in the borehole from the top of the aquifer to within 1.5 meters (5 feet) of the surface. The remaining 1.5 meters (5 feet) shall be abandoned by:

1) Removing the top 1.5 meters (5 feet) of the casing, capping the well 1.5 meters (5 feet) below the surface with concrete at least 10 centimeters (4 inches) thick and filling the remainder of the hole with native soil;

2) Filling the remainder of the cavity with inert material and installing a permanent water-tight cover at the top of the casing;

3) Filling the entire borehole with concrete, neat cement, or other impervious material.

Where a well penetrates a confined aquifer, the impervious strata shall be plugged with concrete, neat cement or other approved material. The plug shall not be less than 1.5 meters (5 feet) in length. The top of the well shall be filled and capped as described in the preceding paragraphs.

NEVADA

The abandonment of oil, gas or water wells, dry holes and seismic exploration wells in the state of Nevada is directed by the "Nevada Oil and Gas Conservation Law and General Rules and Regulations." A notice of intention must be filed with the Oil and Gas Conservation Commission and approval must be obtained before work shall commence. The abandoned well shall be plugged in a manner which will confine all gas, oil and water in the separable strata originally containing them. Upon completion, a form stating that the work has been terminated must be filed with the Commission.

NEW HAMPSHIRE

New Hampshire has no state laws regarding well abandonment. It does require that open wells be fenced or protected to prohibit the danger of injury to people and animals.

NEW JERSEY

The owner of any well in the state shall, upon abandonment of said well or test hole, notify the Division of Water Resources, Department of Environmental Protection, and they shall effectively seal and fill such wells. The Division of Water Resources also has the power to order the sealing of any abandoned well when, in its judgment, the condition of the well endangers or threatens to endanger the subsurface or percolating waters by intrusion of salt water or from other causes, or endangers life. The owner of any abandoned well who shall fail or refuse to seal it in the time or manner ordered by the Division shall be subject to a penalty of five hundred dollars for each violation and fifty dollars per day for each day the violation shall continue.

To engage in sealing a well, the contractor must be approved by the Bureau of Water Control of the Division of Water Resources and the operation must be under the immediate supervision of a licensed New Jersey well driller.

Detailed information is presented pertaining to the procedures to be followed for abandoning rock wells and wells in unconsolidated formations. After filling with gravel or concrete, the remaining space at the top of the well shall then be filled with concrete and the top formed to create a concrete slab at least 15 centimeters (6 inches) thick above the top of the casing with a diameter at least 0.6 meters (2 feet) greater than the outer casing.

NEW MEXICO

The state requires that in order to plug a shallow well, it shall be filled to the ground surface or, if the casing is not to be removed, a steel

plate or cap shall be welded to the casing. Artesian wells and exploration wells can only be plugged under the supervision of the State Engineer or his representative, who shall designate the amount of cement to be used and the depths at which cement plugs shall be set.

Comments: By requiring that only a steel plate or cap be placed on an abandoned well with casing, New Mexico is ignoring the fact that the casing will at sometime in the future corrode. Thereafter the well may serve as a conduit for contaminants to enter the aquifer.

NEW YORK

The New York State Department of Environmental Conservation has been delegated the authority to regulate the abandonment of wells. Only Long Island is required to abide by these regulations. The regulations that have been adopted are based on the American Water Works Association Standard for Deep Wells No. A 100-66 (See Appendix B).

NORTH CAROLINA

The well shall be inspected and all obstacles inside shall be removed. Prior to sealing, the well will be chlorinated. Bored wells shall be completely filled with cement grout or dry clay. Wells drilled in unconsolidated formations shall be completely filled with cement grout. Wells constructed in consolidated formations may be filled with sand or gravel opposite the zones of consolidated rock. The top of the sand and gravel shall be at least 1.5 meters (5 feet) below the top of the consolidated rock. The remainder of the well shall be filled with cement grout. The owner of the well shall be responsible for abandonment except when agreed upon in a written contract with a driller, or when abandonment is the result of drilling in an improper location, or the driller fails to comply with the provisions of the contract between he and the owner.

Comments: North Carolina requires that the well be disinfected before sealing. This is an extremely valuable requirement that is often neglected in state well abandonment regulations. Unfortunately, the statute is still not thorough enough. Not only should the well be disinfected before sealing, but all materials placed in the well and all tools used in the abandonment process should be sterilized.

NORTH DAKOTA

The state requires that all abandoned wells shall be sealed by restoring as far as possible the geological conditions that existed before the well was drilled. Requirements and procedures for well abandonment have been adopted from the American Water Works Association Standard No. A 100-66 (See Appendix B).

OHIO

The Ohio Environmental Protection Agency is charged with the authority to write legislation and enforce abandoned well regulations. All abandoned wells and test holes shall be either completely filled with grout or such other materials as will prevent contaminants from entering ground water, or shall be maintained in strict compliance with all applicable requirements of Ohio EPA "Modification and Maintenance of Wells." The enforcement of well abandonment regulations is handled on a request or complaint basis through Ohio EPA, or is covered under various county regulations.

OKLAHOMA

The owner of a well is responsible for its abandonment. Notification of well abandonment is required and plugging shall be supervised by a state representative. The well shall be plugged in a manner that will prevent the migration of fluids between formations. All liquids shall be displaced from the well and the well shall be filled with drilling mud. Any uncovered hole below the shoe of any casing to be left in the well shall be filled with cement to a depth of at least 15 meters (50 feet) above the shoe of the casing. The well bore shall be filled with cement from the base of the screen or liner to a point at least 15 meters (50 feet) above the liner or screen. All fresh water zones encountered in the well shall be sealed off and protected by adequate casing extending from a point at least 15 meters (50 feet) below the base of the lowest fresh water zone to within one meter (3 feet) of the top of the well bore and by completely filling the annular space behind such casing with cement.

If the surface or other casing in the well meets these requirements, a cement plug may be set at least 15 meters (50 feet) below the shoe of the casing to extend at least 15 meters (50 feet) above the shoe of the casing. If the casing and cement behind the casing do not meet the requirements of this subsection, the well bore shall be filled with cement from a point 15 meters (50 feet) below the base of the lowest fresh water zone to a point 15 meters (50 feet) above the shoe of the casing. The well bore shall, in all events, be filled with cement from a point one meter (3 feet) below ground surface to a point 10 meters (33 feet) below ground surface. All intervals between cement plugs in the well bore shall be filled with mud. Any "rat" or "mouse" hole used in the drilling of a well with rotary tools shall be filled with mud to a point 2.5 meters (8 feet) below ground level and with cement from such a point to a point one meter (3 feet) below ground level and then shall be filled in with earth above the top of the cement. The top of the plug of any plugged well shall show clearly by permanent markings, whether inscribed in the cement or on a steel plate embedded in the cement, the well number and date of plugging.

Within 15 days after a well has been plugged, the owner or operator shall file a plugging record in duplicate with the Board. If a complete and correct log of the well is not on file with the Board, then the owner at the time of plugging shall furnish and file a complete and correct log thereof or the best information available. The well bond will be released only when the requirements of this rule have been met.

OREGON

Oregon's Water Resources Department has adopted the well abandonment procedures contained in the Manual of Recommended Water Well Construction Standards, prepared by the National Water Well Association for the Environmental Protection Agency (See Appendix A).

Comments: Oregon has found that policing and enforcement of the well construction standards is very difficult, particularly in the placement of adequate casing seals. Usually, it is not

possible to have the well inspector available at the drilling site at the precise moment when the casing and well grouting procedures are performed.

PENNSYLVANIA

The Commonwealth of Pennsylvania has revised their well abandonment regulations to conform to the recommended procedures described by the National Water Well Association for the Environmental Protection Agency (See Appendix A).

RHODE ISLAND

The Rhode Island Department of Health requires that only public supply wells be abandoned following American Water Works Association Standard No. A 100-66 (See Appendix B).

SOUTH CAROLINA

South Carolina has no regulations governing abandonment of wells. However, when a ground water contamination problem results from an abandoned well, the department of Health and Environmental Control recommends that the procedures be utilized as outlined in the Manual of Recommended Water Well Construction Standards, as prepared by the National Water Well Association in conjunction with the Environmental Protection Agency (See Appendix A).

SOUTH DAKOTA

Abandoned wells will be plugged using methods and material specified by the Water Rights Commission. Each abandoned well is handled on an individual basis so there are no written plugging procedures. An abandoned well is to be plugged in a manner that will prohibit leaking of its water underground or over the surface, and inhibit inter-aquifer exchange.

TEXAS

The Texas Water Development Board has the authority to regulate and enforce well abandonment. The Board requires that the landowner or person having the well drilled shall be charged with the responsibility of having the well sealed.

In the event undesirable water is encountered in a zone overlying a fresh-water zone, the well shall be filled with cement to the land surface; or cement shall be placed opposite the fresh-water zone to some distance above the uppermost fresh-water zone and the remainder of the hole filled with heavy mud to form a base for a cement plug, which shall extend from some distance below the undesirable water zone to the land surface or some distance above the undesirable water zone, and the remainder of the hole filled with heavy mud. The method used to plug the hole shall be selected based on the condition of the borehole, lithology of the section penetrated, or the hydrostatic pressures in the aquifers.

In the event undesirable water is encountered in a zone underlying a zone of fresh water, the well shall be filled with cement to the land surface; or the lower part of the well shall be filled with find sand, clay or heavy mud to form a base for a cement plug which shall be placed opposite the fresh-water zone, extending from below the fresh-water zone to the land surface or extending from below to some distance above the fresh-water zone and the remainder of the hole filled with heavy mud; or cement shall be placed opposite the undesirable water zone and extending upward to the base of the lowermost fresh-water zone, or to some distance above the undesirable water zone and the remainder of the hole filled with heavy mud. The method used to plug the well shall be selected based on the condition of the wellbore, lithology of the section penetrated, or the hydrostatic pressures in the aquifers.

When an existing water well is deepened and encounters undesirable water, the zone contributing undesirable water to the deepened well shall be isolated from the wellbore by cement extending to the land surface, or to the base of the lowermost fresh-water zone, or to some distance above the undesirable water zone. The method selected shall be based on the condition of the wellbore, lithology of the section penetrated or the hydrostatic pressures in the aquifers.

In the event that the use of a well penetrating an undesirable water zone is permanently discontinued, all of the casing shall be removed from the well and the well plugged in accordance with Water Development Board Rules discussed in the three preceding paragraphs; or the casing below, opposite and above the undesirable water zone perforated and squeeze-cemented, to confine the undesirable water to its zone of origin and the well filled with heavy mud; or all porous zones encountered in the drilling of the well shall be squeeze-cemented and the entire wellbore filled with heavy mud.

All sand point wells drilled or driven for the purpose of producing fresh water which encounter undesirable water shall be filled from total depth to the land surface with cement or heavy mud.

In the event an uncased well is plugged in such a manner that cement does not extend to the land surface, the uncemented part of the wellbore shall be filled with mud and the well capped with a cement plug at or near the land surface in such a manner as to prevent the entrance of surface water, or other materials and objects, into the well. The capped part of the well shall be capable of supporting a static weight of 226.8 kilograms (500 pounds).

In the event a well equipped with casing at the land surface is plugged in such a manner that cement does not extend to the land surface, the outermost casing shall be fitted with a water-tight cap, at or near the land surface and the annular space between the casing and the wall of the borehole filled with cement in such a manner as to prevent the entrance of surface water, or other materials and objects, into the well. The well so capped must be capable of supporting a static weight of 226.8 kilograms (500 pounds).

Comments: The Texas Water Development Board is in charge of enforcing the well abandonment regulations. When the Board receives a request to have a well abandoned, it will make

recommendations on how the well shall be plugged on an individual basis. Recommendations are based on information furnished in the Board's files or information furnished by the well owner. The well construction data is then examined with the available geological and hydrological information. If such data is not present or is not sufficient, then field investigations are conducted in order to make proper recommendations to prevent pollution of the water. By considering each well abandonment case individually, coupled with an excellent outline of well abandonment procedures, the state has been effective in reducing potential ground water contamination from abandoned wells.

TENNESSEE

The state of Tennessee requires that test wells and ground water sources which are not in use shall be sealed by methods which will restore the controlling geological conditions that existed before the wells were constructed. The purpose of sealing the wells is to prevent exchange of water from one geologic strata to another. The well should be filled with material which shall prevent contamination of the ground water. Concrete is the preferred fill material.

UTAH

The Office of the State Engineer regulates well abandonment. The state requires that the abandoned well shall be filled in a manner to prevent the well from becoming a channel through which fluids can migrate vertically and become a possible source of contamination to fresh ground water supplies.

The well casing shall be removed during abandonment. As the casing is being withdrawn, the well shall be plugged with cement grout, concrete or puddled clay. All gravel-packed wells shall be pressure-grouted throughout the perforated sections of the well casing. The remainder of the well shall be filled with cement grout, concrete or puddled clay. Procedures for abandonment of drilled and jetted wells is similar to that of gravel-packed wells. Abandonment of artesian wells should be done by placing cement grout or concrete plugs in the confining stratum overlying the artesian zone to prevent subsurface leakage from the artesian zone. The remainder of the well shall be filled with cement grout, concrete, or puddled clay. A contractor who fails to abide by state regulations may have his license revoked.

VIRGINIA

The Virginia Department of Health and the Virginia State Water Control Board require that abandoned wells be sealed by methods which will restore the controlling geological conditions that existed before the construction. All abandoned wells shall be sealed to prevent exchange of water from one geological strata to another. The abandoned wells shall be filled with material which will prevent contamination of ground water. Concrete is the preferred material.

WASHINGTON

The state requires that all abandonment procedures be recorded and reported to the state. The remainder of the state's regulations are nearly identical to that of the state of Utah.

WEST VIRGINIA

West Virginia requires that only abandoned oil and gas wells be plugged. There is no legislation regulating water wells or boreholes.

Before an oil or gas well can be plugged or abandoned, the owner must acquire a permit or verbal permission from the Division of Oil and Gas of the Department of Mines. In addition, a bond or approved security must be filed before a plugging operation can begin.

The state requires all oil and gas wells be abandoned in a manner that will prevent migration of oil, gas, water (fresh or salt) or any injected liquid or gas to any strata other than the stratum or strata in which they occur or have been placed. Only non-porous materials shall be used as plugs. Upon completion of the plugging operation, a report of the procedure must be filed with the Division of Oil and Gas.

WISCONSIN

The state of Wisconsin, Department of Natural Resources, requires that when a well is permanently abandoned, the owner must fill and seal the well in such a manner as to prevent it from acting as a channel for contamination or vertical movement of water by one of the following methods:

1) Wells in drift or unconsolidated formations shall be filled with concrete or clean puddled clay in which case at least a 6 meter (20 foot) plug of concrete shall be poured at the top of the well. If possible, the inner well casing shall be removed. The top 2 meters (7 feet) of curbing in dug wells shall be removed prior to plugging.

2) In limestone strata, wells shall be filled entirely with concrete. As an alternative, layers of concrete and gravel or stone aggregate can be used, except for the top 6 meters (20 feet) of the well, which must be filled with concrete. An exception to this may be made where the well casing is set in rock and sealed in place with cement grout, in which case a concrete plug shall be placed extending at least 6 meters (20) feet above and below the bottom of the casing. The remainder of the cased portion up to 6 meters (20 feet) shall also be filled with concrete.

3) Sandstone formations shall be filled with concrete. As an alternative, disinfected sand or pea gravel may be used except that the top 6 meters (20 feet) of the formation, and the entire cased portion, shall likewise be filled with concrete.

4) Shale rock, granite and quartzite formation wells use the same procedure as with limestone formation wells.

5) Where formations are variable, the limestone, sandstone, shale, granite and quartzite strata shall be filled in compliance with preceding sections, providing concrete or concrete grout plugs at least 12.2 meters (40 feet) in depth, extending at least 6 meters (20 feet) above and below the point of surface contact between every recognized different geologic formation--where the alternative methods to filling the well entirely with concrete are selected.

6) Procedures for plugging flowing wells are the same as above for the same strata except that all cement grouts must be emplaced under pressure.

A report shall be made to the department by the owner of every well which has been permanently abandoned or temporarily removed from service. Such reports shall include a detailed description of location, construction and geologic features, and method of sealing. Wisconsin has penalties to deal with contractors who fail to comply with teh above regulations, but there is no inspection program.

WYOMING

The state of Wyoming has the following provisions in its regulations for water well abandonment.

1) It is the responsibility of the well owner to properly care for a well when it is not being used to supply water for beneficial use. It is the responsibility of the driller to properly fill and seal (destroy) any test well not converted into a permanent water well.

2) When a well is temporarily removed from service, it shall be kept in a state of good repair. The top of the well shall be sealed with a watertight cap or seal to prevent the entrance of pollutants.

3) When any well, including any test well, is to be permanently removed from service, it shall be destroyed, to prevent the well from becoming a channel that allows vertical movement of water or that allows contamination of the ground water supply. An uncased well shall be destroyed by filling it completely with grout, cement or concrete grout, drilling mud, or bentonite.

4) A cased well in unconsolidated formations shall be destroyed by placing cement or concrete plugs opposite all perforations or screens. The rest of the well shall be filled with grout, cement or concrete grout, drilling mud, or bentonite.

5) A well in consolidated formations shall be destroyed by filling it with grout, cement or concrete grout, drilling mud, or bentonite. Any section of the well intersecting cavernous or creviced rock shall be filled with concrete or cement grout, or alternate layers of cement grout and gravel or stone aggregate. A concrete or cement plug shall extend to at least 3 meters (10 feet) above the cavernous zone and 3 meters (10 feet) below the cavernous zone or to the bottom of the well, whichever distance is less.

6) An artesian well shall be destroyed in such a manner that a cement or concrete plug completely seals the artesian aquifer and extends above the artesian zone for a minimum of 3 meters (10 feet). This seal shall also extend 3 meters (10 feet) below the artesian zone or to the bottom of the well, whichever distance is less. If necessary to stop surface or subsurface leakage from the artesian zone, the entire zone shall be pressure-grouted. The remainder of the well shall be filled with grout, cement or concrete grout, drilling mud, or bentonite.

7) A gravel packed well shall be destroyed by pressure-grouting the entire perforated or screened section of the casing. The remainder of the well shall be filled with grout, cement or concrete grout, drilling mud, or bentonite.

Any hole drilled for mineral exploration shall be capped upon abandonment. In addition, all such holes shall be located to the nearest 61 meters (200 feet) and their existence shall be made known to the state engineer.

The plugging of an abandoned mineral exploration hole shall be done in a manner similar to the procedure for water wells. Any person or company who fails to comply with Wyoming regulations is guilty of a misdemeanor punishable by not more than 90 days in jail or a fine of not more than $5,000 or both.

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APPENDIX A

PERMANENT WELL AND TEST HOLE ABANDONMENT

From: Manual of Water Well Construction Practices, U. S. Environmental Protection Agency, Office of Water Supply, EPA-570/9-75-001

PREAMBLE

Unsealed abandoned wells constitute a hazard to public health, safety, welfare, and to the preservation of the ground water resource. The sealing of such wells presents a number of problems, the character of which depends upon the construction of the well, the geological formations encountered, and the hydrologic conditions. To seal an abandoned water well properly, several things must be accomplished: 1) elimination of a physical hazard; 2) prevention of ground water contamination; 3) conservation of yield and maintenance of hydrostatic head of aquifers; and 4) prevention of the intermingling of desirable and undesirable waters.

The basic concept governing the proper sealing of abandoned wells is the restoration, as far as feasible, of the hydrogeologic conditions that existed before the well was drilled and constructed, for an improperly abandoned well might serve as an uncontrolled invasion point for contaminated and polluted water. Any well that is to be permanently abandoned should be completely filled in such a manner that vertical movement of water within the well bore, including vertical movement of water within the annular space surrounding the well casing, is effectively and permanently prevented and the water is permanently confined to the specific zone in which it originally occurred. If all these objectives can be accomplished, all the rules for sealing wells heretofore presented will be fulfilled.

To seal an abandoned well properly, the character of the ground water must be considered. If the ground water occurs under unconfined or water-table conditions, the chief problem is that of sealing the well with impermeable material so as to prevent the percolation of surface water through the original well opening, or along the outside of the casing, to the water table. If the ground water occurs under confined or artesian conditions, the sealing operation must confine the water to the aquifer in which it occurs -- thereby preventing loss of artesian pressure by circulation of water to the surface, to a formation containing no water, or to one containing water under a lower head than that in the aquifer which is to be sealed.

Preparation for Abandonment

Strong efforts should be made to remove all materials from a well which may hinder its proper abandonment. This is especially important where specified zones must be sealed.

If a screen has been installed in the well by telescoping, its recovery is usually possible by installing a string or fishing casing from the top of the well to a sand hitch placed close to the bottom of the screen. Following the setting of the sand hitch, a lifting force, applied either by mechanical or hydraulic jacks, or multiple pulling lines from the casing reel of the drilling machine, will usually withdraw the screen from the well.

In recovering steel casings extending to the surface, the least expensive and least hazardous method is to apply a lifting force to the casing by the use of jacks, or with the drilling machine, or with the two in combination. Still more effective is the use of a jarring head applied at the top of the casing string and used in combination with lifting devices.

Maximum recovery is usually obtained by using a trip-type casing spear actuated by a fishing cable tool string and used in combination with lifting devices. The trip spear is usually limited in its use to recently drilled wells or to those in which the casing is known to be in sound condition. The risk of failure associated with the use of a casing spear increases with the age of the well and the depth at which it is to be used.

It is always good practice to probe the well with a swage of the same diameter as the spear prior to inserting the latter.

The order of descent into the casing for a trip spear string of tools is: 1) trip spear; 2) fishing jars; 3) sinker bar of drill stem; 4) rope socket, which is attached to the drilling line. The swage would replace the spear in the above string of tools.

Abandonment

Borehole Bridging --

To reduce cost of unnecessary backfilling of long sections of borehole, it is often desirable to establish a temporary bridge in the borehole upon which a permanent cement-based bridge can be placed. No organic materials should be used in either the temporary or permanent bridge--except that specially manufactured devices such as cement plugging tools in which neoprene rubber or plastics are used, are acceptable and those greatly facilitate the work. Some of these devices permit establishing the permanent bridge without first having to set a temporary one.

Abandonment of Flowing Artesian Wells --

The flowing artesian well with improperly sealed casing and with water escaping around the outside of the casing either to the surface or to another formation presents a special problem. A necessary first step in bringing the

flow under control is to establish a permanent cement seal between the casing and the point or points from which the water is escaping.

In order to place this seal effectively, the flow must be stopped and the water level lowered in the well. This can be accomplished by several methods. Some of these are: 1) pumping the problem well, thereby producing the necessary drawdown; 2) pumping nearby wells, producing the same effect; and 3) introducing high specific gravity fluids at the bottom of the borehole and filling the hole with the fluid until all flow ceases. The method or methods used will depend in part on the shut-in pressure of the well and the depth to which the water level must be lowered.

The sealing of abandoned wells that have a large movement of water between aquifers or to the surface requires special attention. The movement of water may be sufficient to make the sealing with ordinary metarials and by the usual methods impractical. In such wells, large stone aggregates (not more than 1/3 of the diameter of the hole), lead wool, steel shaving, a well packer, or cast lead plug or bridge should be used to restrict the flow thereby permitting the placement of appropriate sealing material. If preshaped or precast plugs are used, they should be several times larger than the diameter of the well to prevent tilting. The flow of artesian wells to be abandoned can best be stopped with neat cement or sand-and-cement grout piped under pressure or, in some instances, by the use of a suitable well packer or cast lead plug placed at the bottom of the confining formation immediately overlying the artesian water-bearing zone.

In wells in which the hydrostatic head producing the flow is low and in which there is no escape of water below ground, the movement of water can be arrested by extending the well casing to an elevation above the artesian pressure surface. This permits the placement of sealants and fill materials, after which the casing may be cut off at or below ground level.

Abandonment of Other Borings and Holes --

Mineral exploration holes, solution or "in situ" mining wells, dewatering wells, temporary service wells, construction water wells, process wells, and/or other structures that affect the withdrawal from or quality of water in the ground water reservoir, regardless of location or intended life of the structure or hole, should be abandoned as described herein for water supply wells.

Functions of Seals --

Three basic types of seals -- distinguished by their functions -- may be used in a properly abandoned well. They are:

A. Permanent Bridge-Seal: The deepest cement seal to be placed in the well, this seal serves two purposes: it forms a permanent bridge below which a considerable volume of unfilled hole may remain and upon which fill material may be safely deposited; and it seals upper aquifers from any aquifer(s) which may exist below the point of sealing (See Fig. 1).

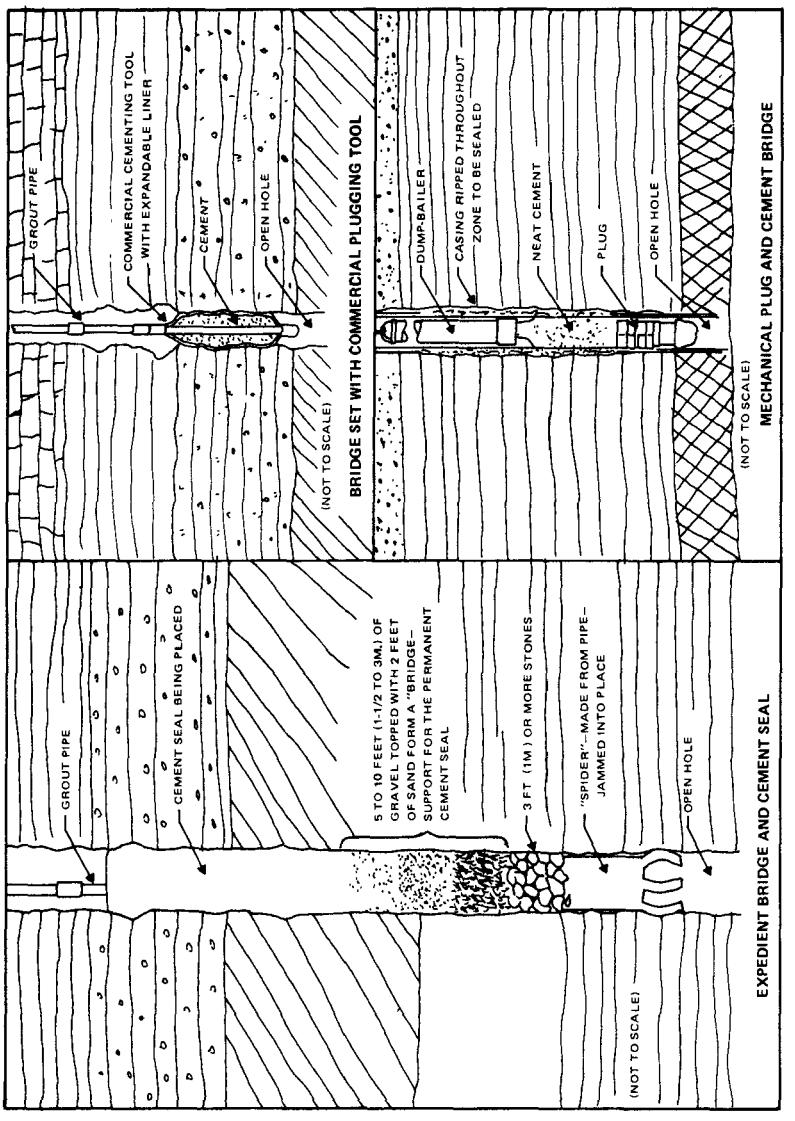

Figure 1. Permanent Bridge Seals.

B. Intermediate Seal: This seal is placed between water-bearing formations which have, or are believed to have, different static heads. Its function is to prevent the inter-aquifer transfer of water (See Fig. 2).

C. Seal at Uppermost Aquifer: This seal is placed immediately above the uppermost aquifer penetrated by the bore hole. Its function is to seal out water from the surface and from shallower formations. In flowing artesian wells, it is designed to prevent the escape of water to the surface, or to shallower formations (See Fig. 3).

Each abandonment effort should be considered an individual problem, and methods and materials should be selected only after detailed study of both construction and hydrogeology. Whenever there is doubt about either the construction or the hydrogeology involved, the choices of materials and procedures should be those affording the greatest probability for successful sealing.

AQUIFER SEALING CRITERIA

56.100-000-000 Aquifer Sealing Criteria: Aquifers shall be filled with disinfected, dimensionally stable materials, compacted mechanically if necessary to avoid later settlement. (Cement, cement-and-sand, and concrete do not require disinfection.)

Disinfection of aquifer fill materials shall be accomplished by using chlorine compounds such as sodium hypochlorite or calcium hypochlorite. Aquifer fill materials shall be clean (relatively free of clays and organic materials) before placement in the well. Disinfection shall be accomplished by dissolving sufficient chlorine compound to produce a calculated concentration of at least 100 mg/l available chlorine in double the volume of water in the well. The fill material shall be placed in the well after the water in the well has been so treated.

PERMANENT BRIDGES

56.010-000-000 Permanent Bridges: Permanent bridges may be used to avoid having to fill very deep holes below the deepest point at which a permanent seal is required. Permanent bridges shall be composed only of cement or cement-bearing minerals. The cement shall be allowed to harden for at least 24 hours, if Type I cement is used, or for at least 12 hours if Type III (highly early strength) cement is used, before backfilling is continued. Temporary bridges used to provide a base for the permanent bridge shall consist only of inorganic materials--except those patented devices containing expandable neoprene, plastic, and other elastomers, which are specifically designed and accepted for use in well construction.

PLACEMENT OF GROUT

56.001-000-000 Placement Operations: Concrete, sand-and-cement grout, or cement grout used as a sealing material in abandonment operations shall be introduced at the bottom of the well or interval to be sealed (or filled) and

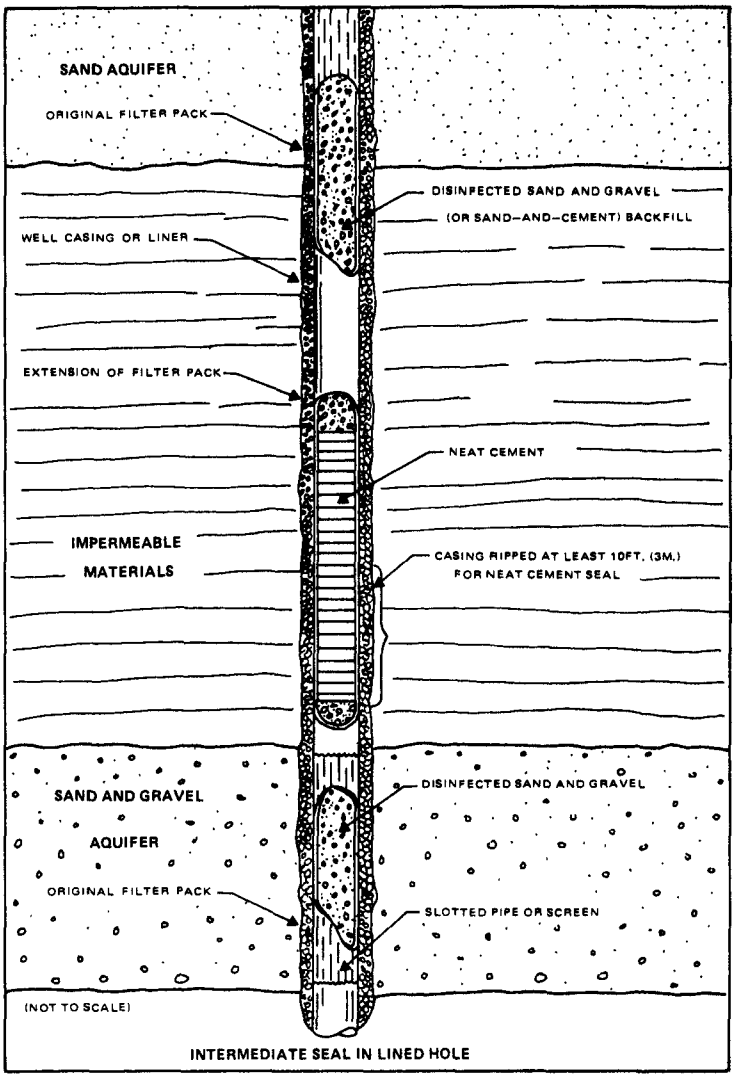

Figure 2. Intermediate Seals.

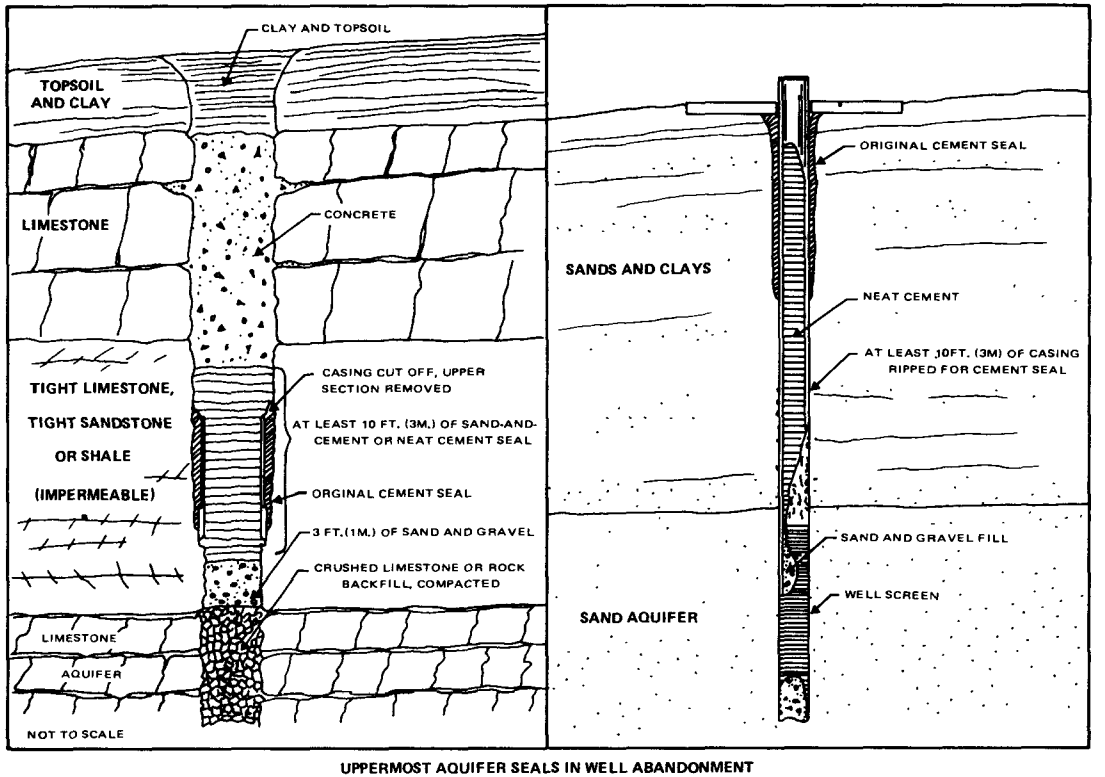

Figure 3. Uppermost Aquifer.

placed progressively upward to the top of the well. All such sealing materials shall be placed by the use of grout pipe, tremie, cement bucket or dump bailer, in such a way as to avoid segregation or dilution of the sealing materials. Dumping grout material from the top shall not be permitted.

Seals intended to prevent vertical movement of water in the well or bore hole shall be composed of cement, sand-and-cement, or concrete -- except that where such seals must be placed within casings or liners, only neat cement or grout may be used. The cement-water ratio shall be that specified in Article 48.100-000-000. Cement seals shall be placed by means of pumping through drop-pipe or by use of a dump-bailer, with placement beginning at the bottom and continuing upward. The minimum cement seal length, wherever dimensions permit, shall be 3 meters (10 feet).

56.002-000-000 Intermediate Seals: Intermediate seals of cement, sand-and-cement, or concrete shall be placed in impermeable strata between aquifers which are identifiable as, or are suspected of being, hydraulically separated under natural, undisturbed conditions. Once the required cement seal has been installed, the remainder of the impermeable zone or non-producing zone between aquifers shall be filled with sand, sand and gravel, or cement-bearing mineral material.

56.003-000-000 Seal at Uppermost Aquifer: A cement, sand-and-cement, or concrete seal shall be installed in the least permeable zone immediately above the uppermost water-producing zone. Such seals shall be placed only in quiescent (non-flowing) water. [See Preamble (56.) for instructions on how to seal flowing wells.]

56.004-000-000 Seals Placed Within Casing, Liners, Filters, etc.: Seals which must be placed in casing, liners, or filters require special attention. The material between the well and the face of the bore hole shall be thoroughly perforated, ripped, or otherwise disintegrated as the necessary first step. Neat cement only, or neat cement with a maximum of 5 percent by weight of commercially processed bentonite clay, shall be used as the seal. Either of two methods may be used.

1) The calculated amount of grout required to fill the well interval plus the annular space outside the lining shall be placed within the space to be cemented, running the cement through a special cementing packer manufactured for this purpose and installed immediately above the perforated or ripped zone. The cement shall be injected at a pressure calculated to be at least 3.5 Kg/cm^2 (50 psi) greater than the normal hydrostatic pressure within the well at the point of injection.

2) The calculated amount of cement grout required to fill the casing interval plus the annular space outside the lining, plus sufficient cement grout to fill an additional 3 meters (10 feet) of the lining, shall be introduced at the bottom of the interval to be cemented.

PLACEMENT OF FILL

56.000-100-000 Non-Producing Zones: Non-producing zones below the top of the uppermost aquifer shall be filled with dimensionally stable materials such as sand, sand-and-gravel, cement, cement-and-sand, or concrete. Non-producing zones above the uppermost aquifer seal shall be filled with materials less permeable than the surrounding undisturbed formations. The uppermost 1.5 meers (5 feet) of the bore hole (at land surface) shall be filled with a material appropriate to the intended use of the land.

SPECIAL CONDITIONS

56.000-010-000 Pre-Existing Contamination: An abandoned well which has already been affected by salt water intrusion or any other contaminants shall be considered a special case, and the method of filling and sealing such wells shall be subject to individual review and written approval by the regulatory agency involved.

In the sealing of a double or multiple cased well, the CONTRACTOR shall submit a drawing thereof with a description of the proposed procedure and materials to be used, for prior approval by the regulatory agency involved.

Mineral exploration holes, solution or "in situ" mining wells, dewatering wells, temporary service wells, construction water wells, process wells, and/or other structures which affect the withdrawal or quality of ground water, or the elevation of the water table, regardless of location or intended length of life of the structure, shall be abandoned according to standards and minimums as described herein for water supply wells.

WELL ABANDONMENT RECORDS

56.000-001-000 Recording Location of Abandoned Well or Bore Hole: Before equipment is removed from the site, the exact location of the abandoned well or hole shall be determined and recorded, "tying in" the location with permanent reference points, or as prescribed by the state or local regulatory agency. All information relative to the abandonment procedures and the location of the abandoned well shall be prepared and assembled as prescribed by the state or local regulatory agency, with copies supplied to the respective agency and the owner of the land.

APPENDIX B

From: American Water Works Association Standard for Deep Wells
American Water Works Association Standard No. A100-66
Section A1-13: Sealing Abandoned Wells

Section A1-13.1 - General: Unsealed abandoned wells constitute a hazard to public health and welfare. The sealing of such wells presents a number of problems, the character of which depends upon the construction of the well, the geologic formations encountered, and the hydrologic conditions. To seal an abandoned water well properly, several factors must be considered: 1) eliminating physical hazard; 2) preventing contamination of ground water; 3) conserving yield and hydrostatic head of aquifers; and 4) preventing intermingling of desirable and undesirable waters.

The guiding principle to be followed in the sealing of abandoned wells is the restoration, as far as feasible, of the controlling geological conditions that existed before the well was drilled or constructed. If this restoration can be accomplished, all the objectives of sealing wells heretofore presented will be adequately fulfilled.

To seal an abandoned well properly, the ground water conditions at the particular well to be sealed must be recognized and evaluated. Thus, if the ground water occurs under water table conditions, the well must be sealed with impermeable material to prevent the percolation of surface water through the original well opening or along the outside of the casing to the water table. If the ground water occurs under artesian conditions, the driller should be equipped to remove obstructions interfering with sealing operations and to provide for placing the sealing materials in the most effective manner. The sealing operations must confine the water to the aquifer in which it occurs--thereby preventing loss of artesian pressure by circulation of water to the surface--to a formation containing no water, or to one containing water under a lower head than that of the aquifer being sealed.

Usually a well should be checked before it is sealed, to insure freedom from obstructions that may interfere with effective sealing operations. This check is especially important in wells that may conduct contaminated or otherwise objectionable water into aquifers yielding potable waters. Removal of liner pipe from some wells may be necessary to assure placement of an effective seal. If liners or casings opposite water-bearing zones cannot be readily removed, they should be split with a casing ripper to assure the proper sealing of water-bearing zones with the sealing material. At least the upper portion of the casing should be removed to prevent surface water from entering the water-bearing strata by following down the casing. This operation is not always essential if the annular space around the outside of the casing was cemented when the well was drilled.

Concrete, cement grout, or neat cement, when used as a sealing material below the water level in the well, should be placed from the bottom up by methods that will avoid segregation or dilution of material. Piping cementing materials directly to the point of application or placement by means of a dump bailer or tremie is recommended. Other sealing materials referred to hereafter, except mud-laden or special clay fluids, can, as a rule, be gradually introduced into the top of the well.

Employment of a competent well driller to accomplish sealing of a deep or flowing well or one in a creviced formation is usually advisable. His knowledge of well construction and the geologic conditions of the region will be valuable in the proper abandonment of a well, just as it is in the construction of a new well. It may be advantageous to call in a consulting engineer or a representative of the state health department or other department having jurisdiction.

The recommendations contained herein pertain to wells in consolidated and unconsolidated formations, to those of small or large diameter, to test wells, and to so-called "stovepipe wells." Each sealing job should be considered as an individual problem, and methods and materials should be determined only after carefully considering the objectives outlined in the first paragraph of this section.

Section A1-13.2 - Wells in Unconsolidated Formations: Normally, abandoned wells extending only into unconsolidated formations near the surface and containing water under water table conditions can be adequately sealed by filling with concrete, grout, neat cement, clay, or clay and sand. In the event that the water-bearing formation consists of coarse gravel, and producing wells are located nearby, care must be taken to select sealing materials that will not affect the producing wells. Concrete may be used if the producing wells can be shut down for a sufficient time to allow the concrete to set. Clean, disinfected sand or gravel may also be used as fill material opposite the water-bearing formation. The remainder of the well, especially the upper portion, should be filled with clay, concrete, grout, or neat cement to exclude surface water. The latter method, using clay as the upper sealing material, is especially applicable to large-diameter abandoned wells.

In gravel-packed, gravel envelope, or other wells in which coarse material has been added around the inner casing to within 6-9 meters (20-30 feet) of the surface, sealing outside the casing is very important. Sometimes this sealing may require removal of the gravel or perforation of the casing.

Section A1-13.3 - Wells Extending Into Creviced Rock Formations: Abandoned wells that penetrate limestone or other creviced or channelized rock formations lying immediately below the surface deposit should preferably be filled with concrete, grout, or neat cement to assure permanence of the seal. The use of clay or sand in such wells is not desirable because fine-grained fill material may be displaced by flow of water through crevices of channels. Alternate layers of coarse stone and concrete may be used for fill material through the water-producing horizon if limited vertical movement of water in the formation will not affect the quality or quantity of water in the producing wells. Only concrete, neat cement, or grout should be used in this type

of well. The portion of the well between a point 3-6 meters (10-20 feet) below and a point above the bottom of the casing should be sealed and a plug formed of sealing material above the creviced formation. Clay or sand may be used to fill the upper part of the well.

Section A1-13.4 - Wells Extending Into Noncreviced Rock Formations: Abandoned wells encountering noncreviced sandstone or other water-bearing consolidated formations below the surface deposits may be satisfactorily sealed by filling the entire depth with clay, provided there is no movement of water in the well. Clean sand, disinfected if other producing wells are nearby, may also be used through the sandstone up to a point 3-6 meters (10-20 feet) below the bottom of the casing. The upper portion of this type of well should be filled with concrete, neat cement, grout, or clay to provide an effective seal against entrance of surface water. If there is an appreciable amount of upward flow, pressure cementing or mudding may be advisable.

Section A1-13.5 - Wells Extending Into More Than One Aquifer: Some special problems may develop in sealing wells extending into more than one aquifer. These wells should be filled and sealed in such a way that exchange of water from one aquifer to another is prevented. If no appreciable movement of water is encountered, filling with concrete, neat cement, grout, or alternate layers of these materials and sand will prove satisfactory. When velocities are high, the procedures outlined in Sec. A1-13.6 are recommended. If alternate concrete plugs or bridges are used, they should be placed in known non-producing horizons, or, if location of the non-producing horizons is not known, at frequent intervals. Sometimes, when the casing is not grouted or the formation is noncaving, it may be necessary to break or slit the casing to fill any annular space on the outside.

Section A1-13.6 - Wells With Artesian Flow: The sealing of abandoned wells that have a large movement of water between aquifers or to the surface requires special attention. Frequently the movement of water may be sufficient to make sealing by gravity placement of concrete, cement grout, neat cement, clay or sand impractical. In such wells, large stone aggregate (not more than one-third of the diameter of the hole), lead wool, steel shavings, a well packer, or a wood or cast-lead plug or bridge will be needed to restrict the flow and thereby permit the gravity placement of sealing material above the formation producing the flow. If preshaped or precast plugs are used, they should be several times longer than the diameter of the well. This will prevent tilting.

Inasmuch as it is very important in wells of this type to prevent circulation between formations or loss of water to the surface or to the annular space outside the casing, it is recommended that pressure cementing with neat cement using the minimum quantity of water that will permit handling be employed. The use of pressure mudding instead of this process is sometimes permissible.

In wells in which the hydrostatic head-producing flow to the surface is low, the movement of water may be arrested by extending the well casing to an elevation above the artesian pressure surface. Previously described sealing methods suitable to the geologic conditions can then be used.

Section A1-13.7 - Sealing Methods: A number of materials for sealing wells satisfactorily, including concrete, cement grout, neat cement, clay, sand, or combinations of these materials, are mentioned herein. Each material has certain characteristics and distinctive properties; accordingly, one material may be especially suited for doing a particular job. The selection of the material must therefore be based on the construction of the well, the nature of the formations penetrated, the material and equipment available, the location of the well with respect to possible sources of contamination, and the cost of doing the work.

Concrete is generally used for filling the upper part of the well or water-bearing formation, for plugging short sections of casings, or for filling large-diameter wells. Its use is cheaper than neat cement or grout, and it makes a stronger plug or seal. But concrete will not penetrate seams, crevices, or interstices. Furthermore, if not properly placed, the aggregate is apt to separate from the cement.

Cement grout or neat cement and water are far superior for sealing small openings, for penetrating any annular space outside of casings, and for filling voids in the surrounding formation. When applied under pressure, it is strongly favored for sealing wells under artesian pressure or those encountering more than one aquifer. Neat cement is generally prefereed to grout as it avoids the danger of separation.

Clay, as a heavy mud-laden or special clay fluid applied under pressure, particularly for sealing artesian wells, is considered adequate by many competent authorities, although others feel that it may, under some conditions, eventually be carried away into the surrounding formations.

Clay in a relatively dry state, clay and sand, or sand alone may be used advantageously, particularly under water table conditions where diameters are large, depths are great, formations are caving, and there is no need of achieving penetration of openings in casings, liners, or formations, or of obtaining a watertight seal at any given spot.

Frequently combinations of these materials are necessary. The more expensive materials are used where strength, penetration, or watertightness are needed. The less expensive materials are used for the remainder of the well. Cement grout or neat cement is now being mixed with specially processed clays and with various aggregates. Superior results and economies are claimed for such mixtures.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

The impact of unplugged wells on ground-water resources is discussed, including a review of case histories and a survey of state laws concerning well abandonment procedures. Model regulations are suggested to guide those states where existing regulations are ineffective or non-existent.

17. KEY WORDS AND DOCUMENT ANALYSIS

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